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(54) INTERNAL TRANSDUCER ASSEMBLY WITH SLIP RING

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A61B 17/29	(2006.01)
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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,790,095	A	4/1957	Peek et al.
4,421,118	A	12/1983	Dow et al.

(Continued)

FOREIGN PATENT DOCUMENTS

JP	06-209939	A	8/1994
JP	10-262974	A	10/1998

(Continued)

OTHER PUBLICATIONS

International Search Report and Written Opinion issued in PCT/US2013/064570, dated Jan. 24, 2014.

(Continued)

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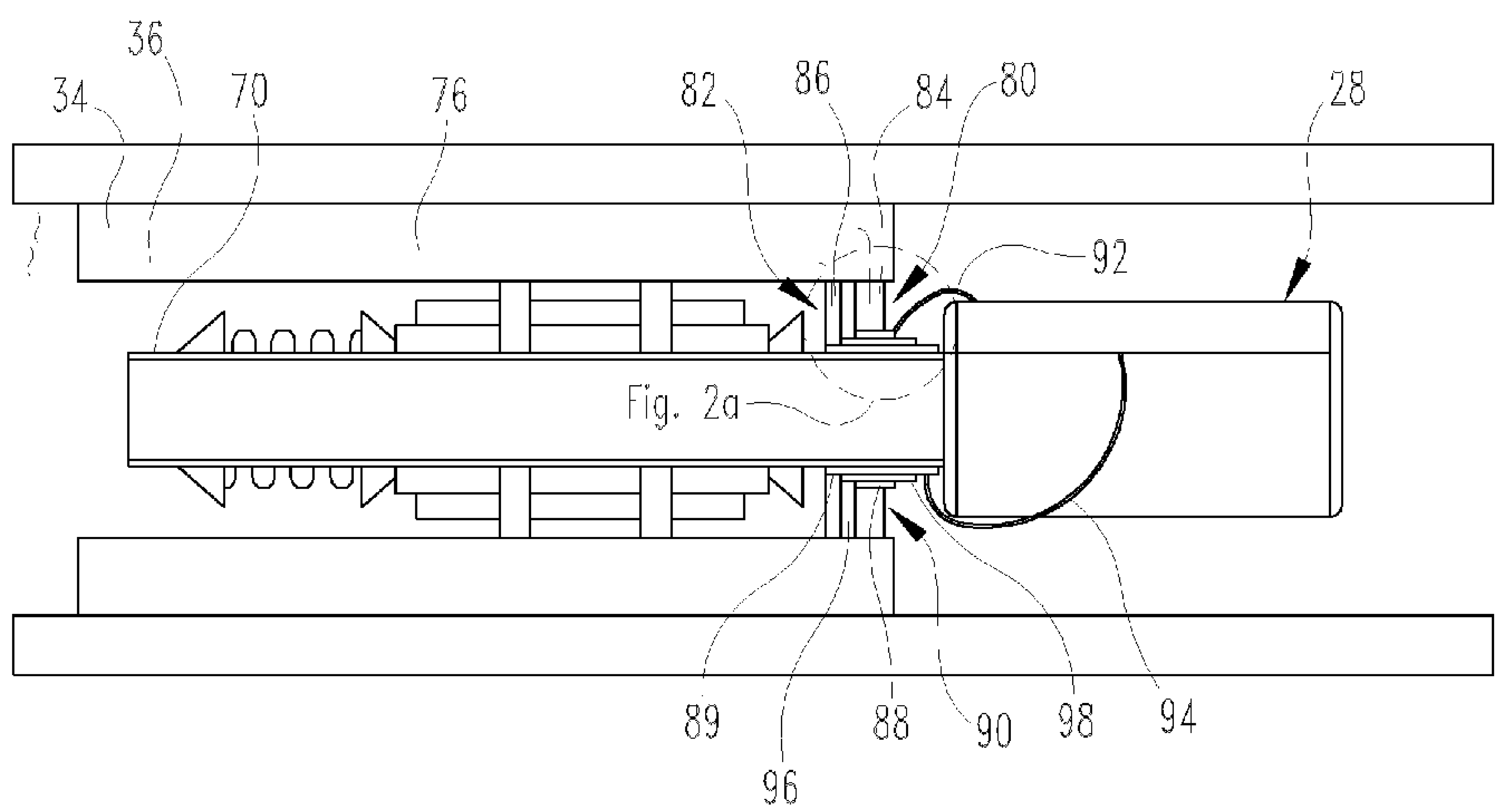
(57) **ABSTRACT**

A device for internal ultrasound imaging including a micromotor rotates a drive shaft and ultrasound transducer. Conductors attach between the transducer and slip ring assemblies. The slip ring assemblies conductively couple the transducer conductors to a set of conductors extending toward a console.

18 Claims, 6 Drawing Sheets



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H01R 39/34	(2006.01)
H01R 43/10	(2006.01)
A61B 17/3207	(2006.01)

(52) **U.S. Cl.**

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(56) **References Cited**

U.S. PATENT DOCUMENTS

4,720,266	A *	1/1988	Leonard et al.	433/126
4,785,816	A	11/1988	Dow et al.	
4,811,617	A	3/1989	Whiteman, Jr.	
4,951,677	A	8/1990	Crowley et al.	
5,237,884	A	8/1993	Seto	
5,373,845	A	12/1994	Gardineer et al.	
5,437,283	A	8/1995	Ranalletta et al.	
5,535,715	A	7/1996	Mouton	
5,611,246	A	3/1997	Long et al.	
5,729,508	A	3/1998	Baker et al.	
6,241,744	B1 *	6/2001	Imran et al.	606/159
6,248,074	B1	6/2001	Ohno et al.	
6,354,814	B1	3/2002	Kaufmann et al.	
6,371,915	B1	4/2002	Koger et al.	
6,684,094	B1 *	1/2004	Lehr et al.	600/407
7,798,971	B2	9/2010	Flesch et al.	
8,206,307	B2	6/2012	Barnard et al.	
8,214,010	B2	7/2012	Courtney et al.	
2002/0082503	A1	6/2002	Chandrasekaran et al.	
2002/0087083	A1	7/2002	Nix et al.	
2002/0143252	A1	10/2002	Dunne et al.	
2005/0203416	A1	9/2005	Angelsen et al.	
2006/0030797	A1	2/2006	Zhou et al.	
2006/0173348	A1	8/2006	Wilser et al.	
2007/0038110	A1	2/2007	Flesch et al.	
2007/0038114	A1	2/2007	Couvillon, Jr.	
2007/0149917	A1	6/2007	Bennett et al.	
2007/0167813	A1	7/2007	Lee et al.	
2007/0167821	A1	7/2007	Lee et al.	
2008/0097403	A1	4/2008	Donaldson et al.	
2008/0177138	A1	7/2008	Courtney et al.	
2008/0221506	A1	9/2008	Rodriguez et al.	
2008/0234716	A1	9/2008	Kiester	
2008/0243035	A1	10/2008	Crunkilton	
2008/0319376	A1	12/2008	Wilcox et al.	
2009/0051121	A1	2/2009	Sokek et al.	
2009/0088631	A1	4/2009	Dietz et al.	
2009/0306518	A1	12/2009	Kurse et al.	
2010/0036258	A1	2/2010	Dietz et al.	
2010/0145310	A1	6/2010	Lee et al.	
2010/0160788	A1	6/2010	Davies et al.	
2010/0179426	A1	7/2010	Davies et al.	
2010/0217125	A1	8/2010	Kadokura et al.	
2010/0234736	A1	9/2010	Corl	
2010/0249601	A1	9/2010	Courtney	
2010/0249602	A1	9/2010	Buckley et al.	
2010/0249604	A1	9/2010	Hastings et al.	
2011/0021924	A1	1/2011	Sethuraman et al.	
2011/0071400	A1	3/2011	Hastings et al.	
2011/0071401	A1	3/2011	Hastings et al.	
2011/0196286	A1 *	8/2011	Robertson et al.	604/22
2011/0237955	A1	9/2011	Dietz et al.	
2011/0263986	A1	10/2011	Park et al.	
2011/0301508	A1	12/2011	Sethuraman et al.	
2012/0108980	A1	5/2012	Shilling et al.	
2012/0172698	A1	7/2012	Teo et al.	
2013/0066304	A1	3/2013	Belson et al.	

FOREIGN PATENT DOCUMENTS

JP	2000-126184 A	5/2000
JP	2001-046375 A	2/2001
JP	2004/129697	4/2004
JP	2007-267998 A	10/2007
WO	WO 2012/061643 A1	5/2012

OTHER PUBLICATIONS

International Search Report and Written Opinion issued in PCT/US2013/064579, dated Jan. 23, 2014.

International Search Report and Written Opinion issued in PCT/US2013/064606, mailed Jan. 8, 2014.

International Search Report and Written Opinion issued in PCT/US2013/064611, dated Jan. 28, 2014.

International Search Report and Written Opinion issued in PCT/US2013/064618, dated Jan. 24, 2014.

International Search Report and Written Opinion issued in PCT/US2013/078245, dated Apr. 25, 2014.

International Search Report and Written Opinion issued in PCT/US2014/023088, dated Aug. 18, 2014, 14 pgs.

International Search Report and Written Opinion issued in PCT/US2014/023092, dated Aug. 12, 2014, 16 pgs.

* cited by examiner

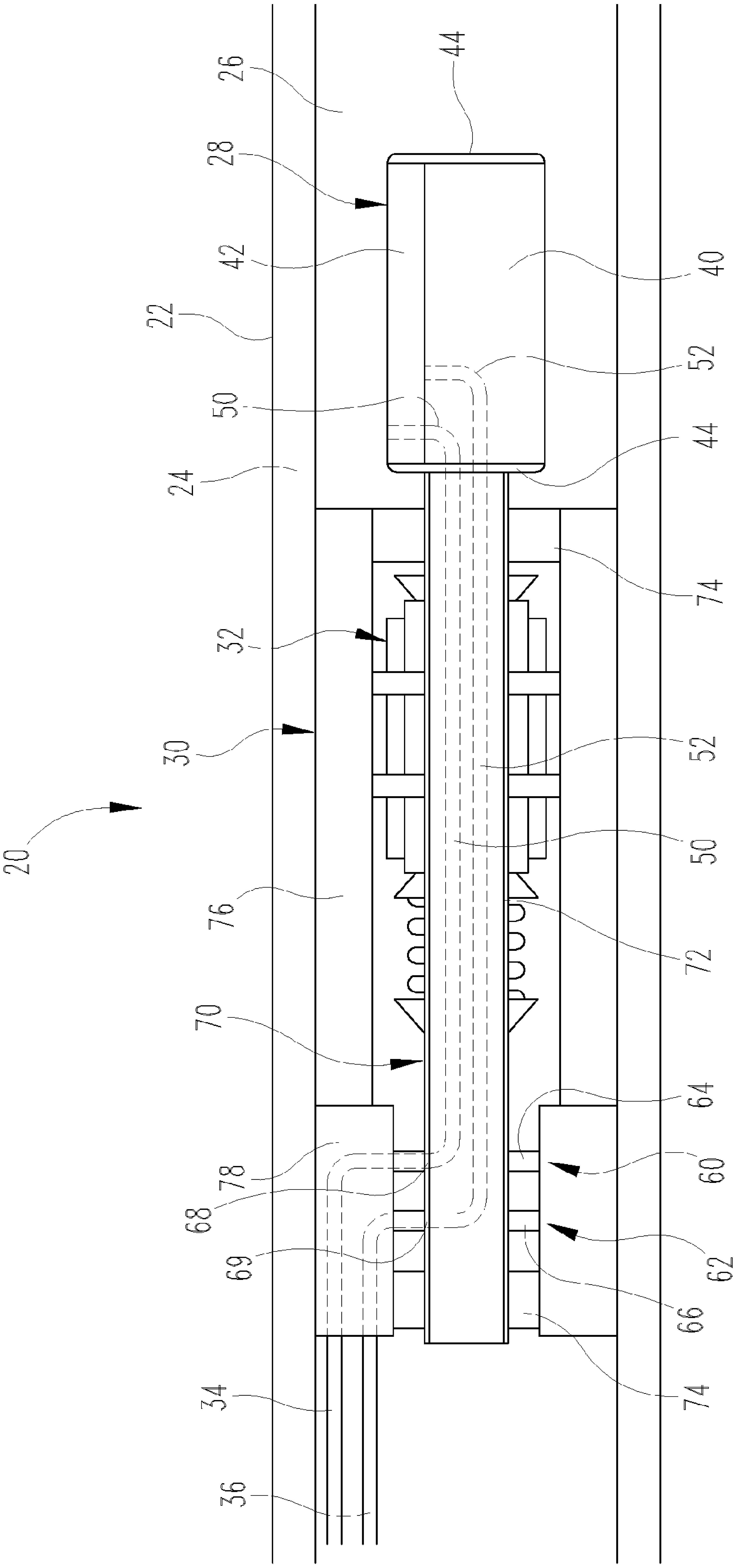
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Fig. 1

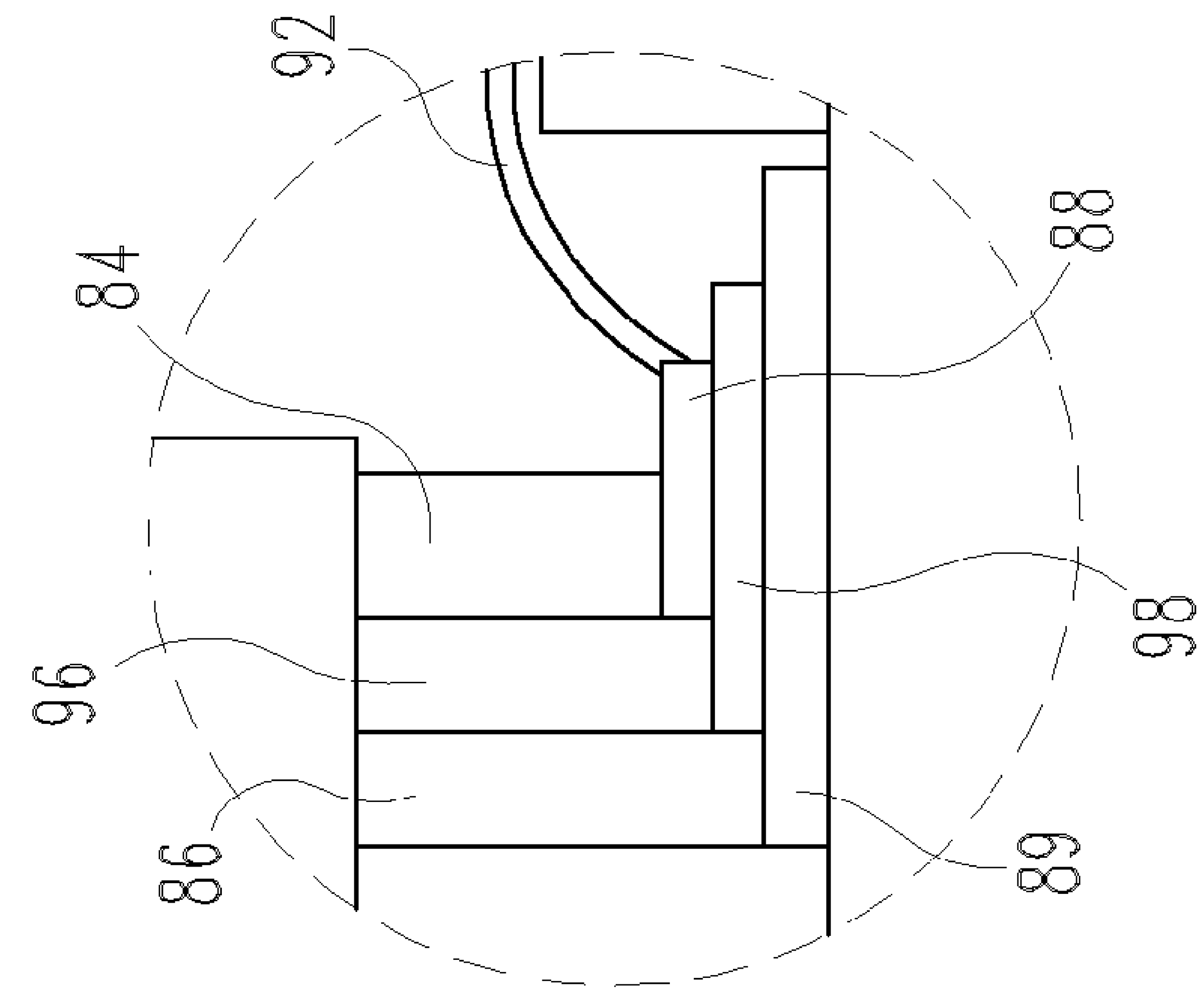
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Fig. 2a

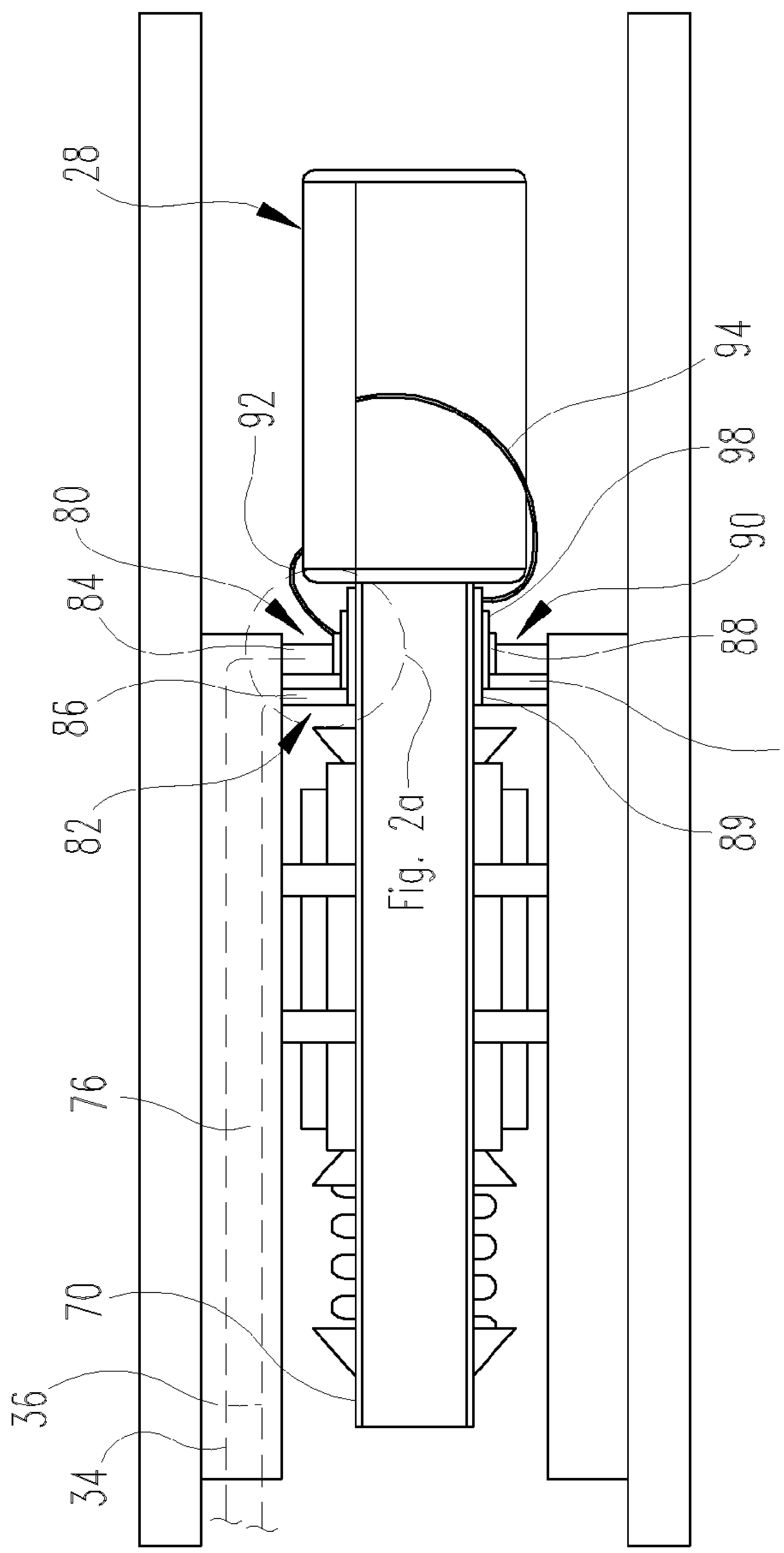
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Fig. 2a
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Fig. 2

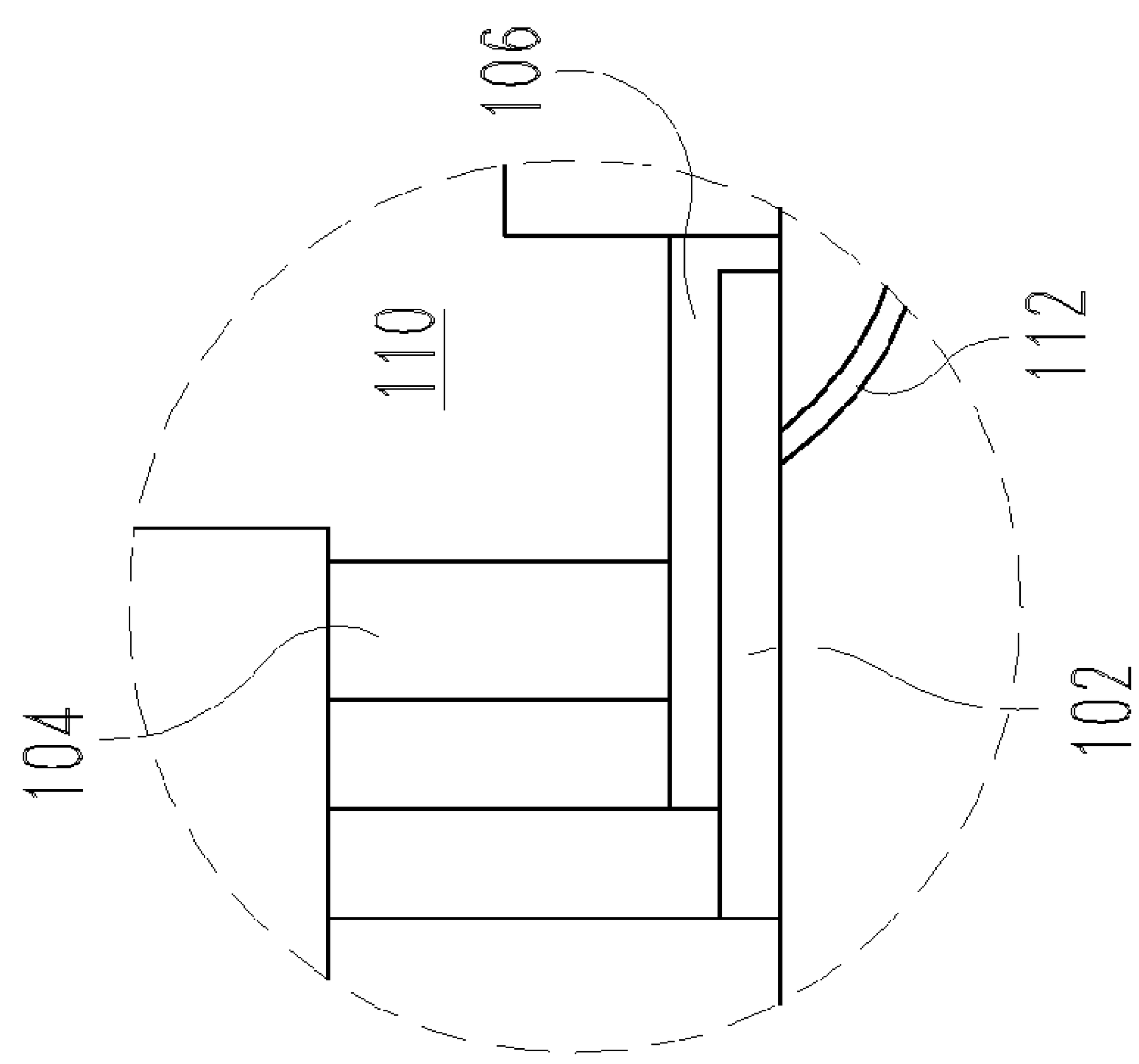
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Fig. 3a

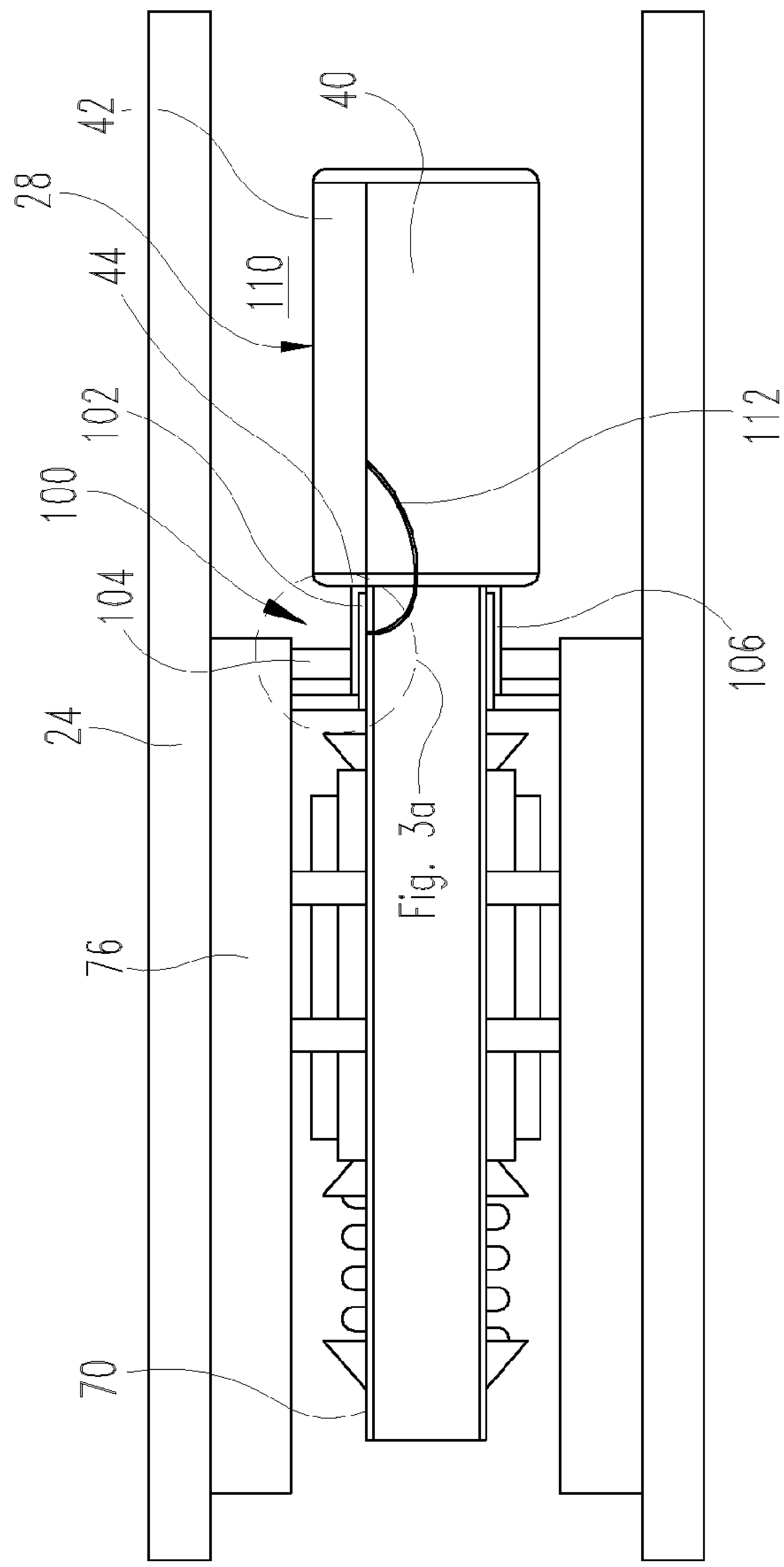
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Fig. 3a
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Fig. 3

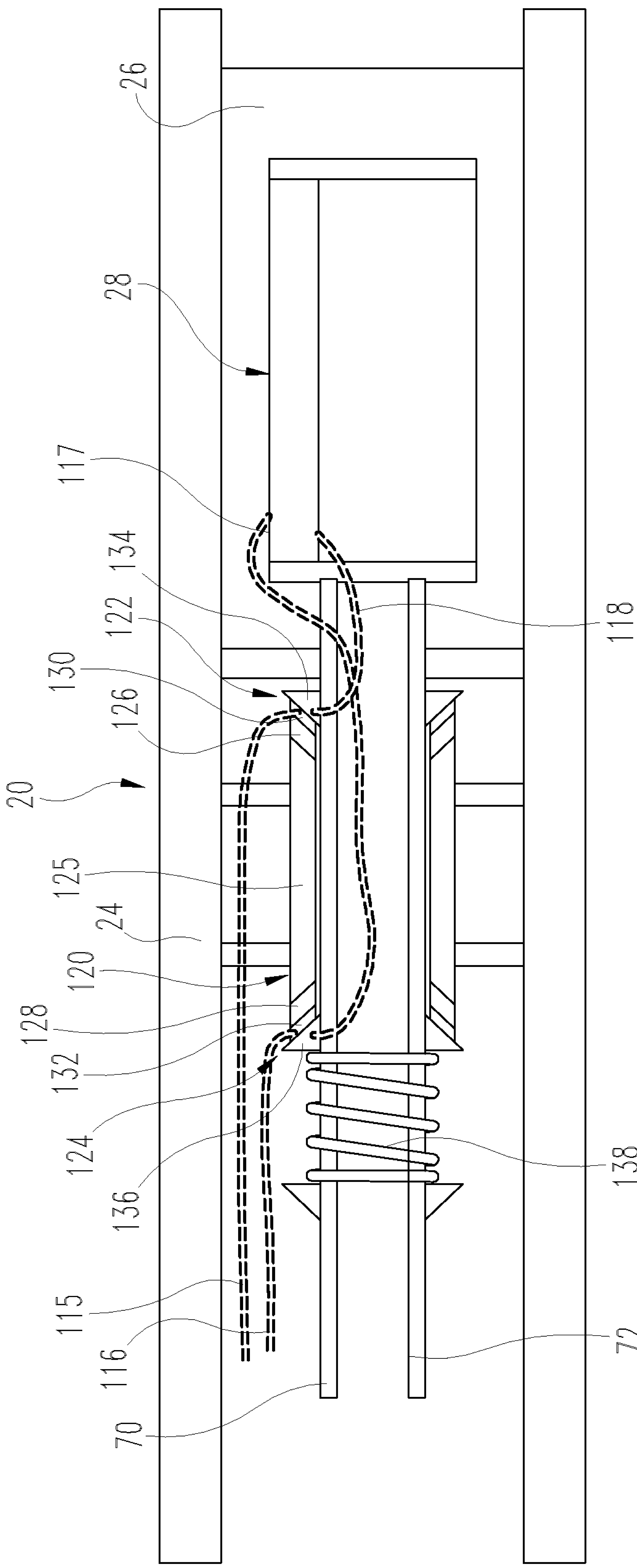
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Fig. 4

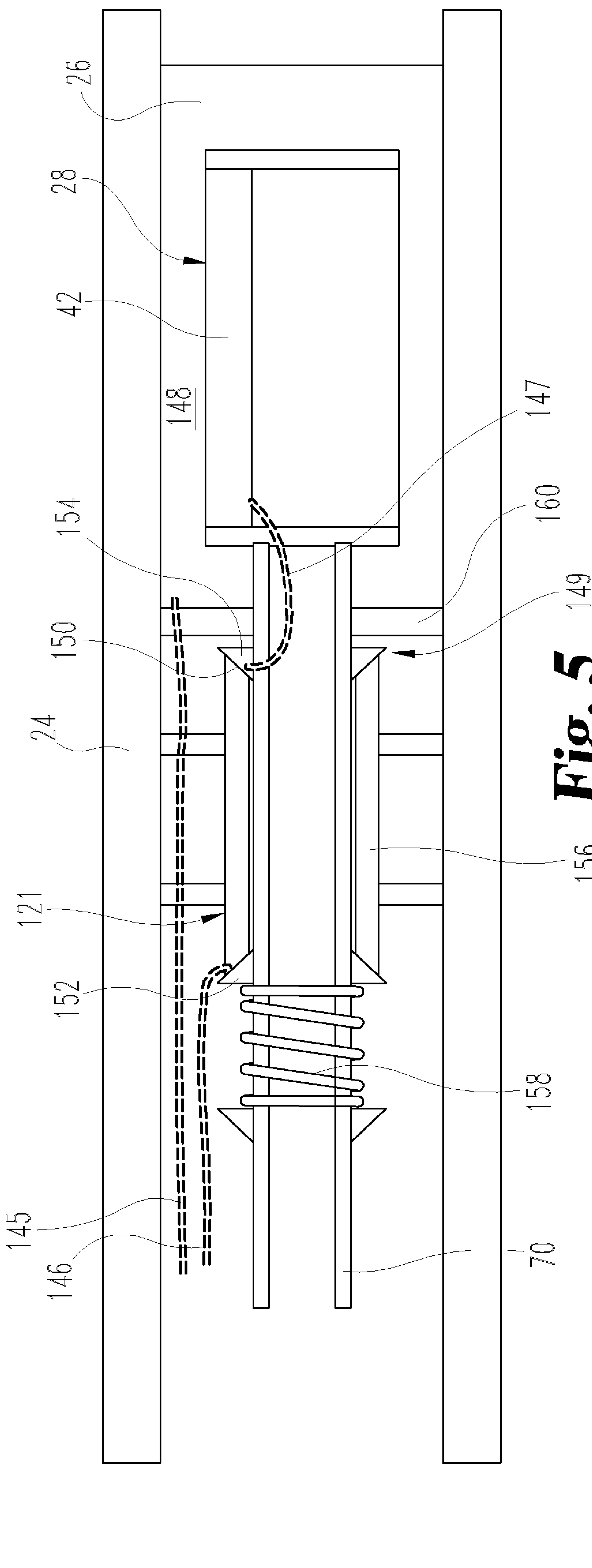

Fig. 5

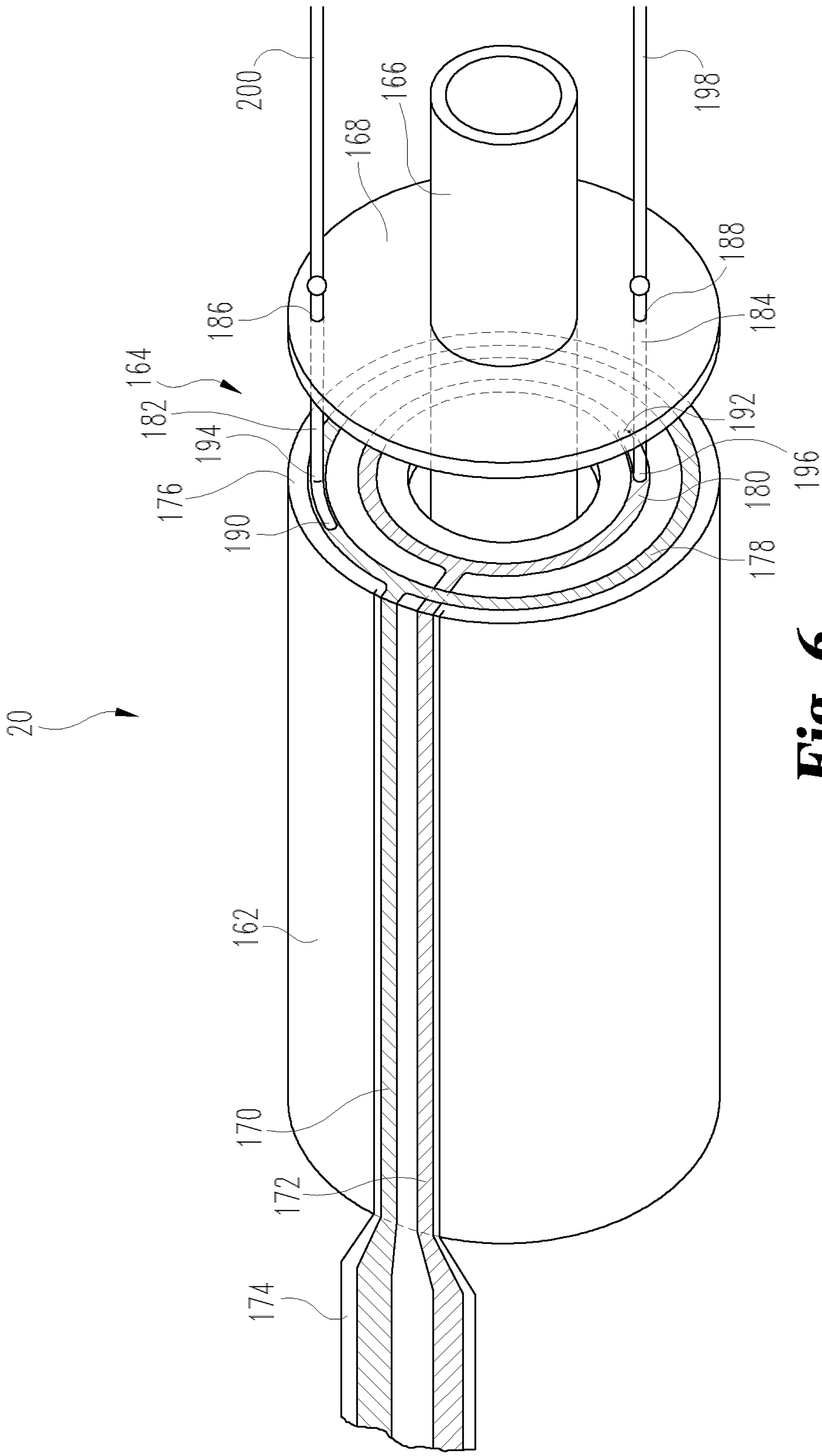
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Fig. 6

INTERNAL TRANSDUCER ASSEMBLY WITH SLIP RING

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application No. 61/714,275 filed Oct. 16, 2012, which is hereby incorporated by reference.

This disclosure concerns devices and methods for using ultrasound within the body of a patient. In particular, it concerns features that allow such devices to be reduced in size for use in small body areas, such as within blood vessels.

BACKGROUND

Ultrasound technology has been used for therapeutic and diagnostic medical procedures, which can include providing imaging of internal portions of a body. Ultrasound procedures typically use a transducer assembly to emit and/or receive signals. In some cases, a stationary transducer assembly can view a full image area due to the particular positioning or electronic steering of the multiple ultrasound elements in an array. Another design includes a rotating transducer assembly having a single ultrasound element which obtains data by mechanically rotating the transducer assembly. In that case, data is obtained by the transducer assembly emitting sequential ultrasound pulses at changing rotational positions. Advantages of the single-element rotational design when compared to an array design include smaller catheter diameter, better image quality, possible higher center frequency, lower cost for the ultrasound imaging console, and less ring down artifacts (dead zone).

Single element designs can also include certain disadvantages, such as non-uniform rotational distortion (NURD). During imaging procedures including a single element design, the ultrasound element is typically rotated with a torque cable. Ultrasound pulses are emitted in an even-spaced time-sequential manner under the expectation of a uniform rotation rate of the ultrasound element. Each reflected ultrasound echo signal represents a portion or scan line of an image. An image processor assembles the data based on the assumption that the data points represent images from evenly-spaced pulses. However, it can be difficult to achieve a uniform rotation rate for the ultrasound element when using a torque cable as a driving means. The ultrasound element can be around one meter from the driving end of the torque cable. Ideally, the torque cable will have sufficient stiffness to provide uniform rotation at both ends while simultaneously allowing maneuverability. However, practically a sufficiently maneuverable torque cable creates a potential for delay in the transferring of torque from one end of the cable to the other, as the cable stores and releases elastic energy, which causes the transducer assembly to rotate at a non-uniform rate even when the rotation source rotates at a uniform rate. The non-uniform rotation rate causes the resulting images to be distorted.

Attempts to create single element designs without torque cables present further problems. Designs which include a microminiature motor positioned near a stationary transducer assembly and a rotating reflector require additional space. In addition, control wires or structural components can cross the viewing window causing a portion of an image to be blocked. Another problem is the possibility of breaking a catheter tip which includes the ultrasound transducer. Designs including a microminiature motor positioned near a

rotating transducer assembly present further problems. Current commercialized designs use costly and bulky rotary transformers to connect stationary electrical wires from a console to a rotating ultrasound element. However, the rotary transformer is among the most expensive components of such imaging systems.

Other problems exist in current designs. Typically, transducer assemblies are positioned in a dedicated catheter. The catheter usually shares the same utility lumen as therapeutic catheters preventing a physician from performing imaging monitoring simultaneously with or during additional procedures, such as, for example, deploying a stent or graft or performing a biopsy.

Thus, there is a need to have an ultrasound system design that could be integrated with a catheter, that is cost effective, small in size, and which produces images free from NURD artifacts and blocked viewing areas.

SUMMARY

Among other things, there are disclosed embodiments of devices for medical ultrasound application within a patient, and methods for making and using them. For example, a device for medical ultrasound in particular embodiments includes a motor operatively coupled with a drive shaft extending substantially along a rotation axis, wherein operation of the motor rotates the drive shaft around the rotation axis, and a transducer configured for transmitting and/or receiving ultrasound signals and operatively coupled with the drive shaft so that the transducer rotates in response to rotation of the drive shaft. A first slip ring assembly having a first rotational contact and a first stationary contact is provided, with the first rotational contact being fixed to the drive shaft and rotatable with the drive shaft relative to and in contact with the first stationary contact, so that the first slip ring assembly maintains an electrical conduction path between the first rotational contact and the first stationary contact while the drive shaft is rotating. A second slip ring assembly having a second rotational contact and a second stationary contact is provided, with the second rotational contact being fixed to the drive shaft and rotatable with the drive shaft relative to and in contact with the second stationary contact, so that the second slip ring assembly maintains an electrical conduction path between the second rotational contact and the second stationary contact while the drive shaft is rotating.

Particular embodiments in which the first and second rotational contacts are electrically conductive layers fixed with respect to the drive shaft are also described. For instance, the first rotational contact can be radially inward of the second rotational contact, with the first and second rotational contacts being separated by an insulating layer. The first rotational contact and the insulating layer have respective lengths measured parallel to a rotation axis of the drive shaft, and examples in which the length of the first rotational contact is larger than the length of the insulating layer are contemplated. Two axially outer portions of the first rotational contact can be exposed from the insulating layer. The length of the insulating layer can be larger than the second rotational contact's length measured parallel to a rotation axis of the drive shaft, e.g. so that two axially outward portions of the insulating layer are exposed from the first rotational contact. Such exposed portions can be used as contact areas for engagement between one or both of the rotational contacts and the respective stationary contact(s). Thus, the first rotational contact and first stationary contact may be in contact with each other at a point on an application side of the insulating layer, and/or the second rotational contact and second stationary contact may be in contact with each other at a point on a control side of the insulating layer. An insulating section is disposed in some embodiments between the first stationary contact and the second stationary contact, and may be disposed to contact the insulating layer. One specific example of such contacts and layers provides the first and second rotational contacts as part of a three-layer coating, the first rotational contact being a radially inward first layer, an insulating layer being a second layer, and the second rotational contact being a radially outward third layer. The insulating layer partially covers the first rotational contact and the second rotational contact partially covers the insulating layer.

Illustrated embodiments include a fluidly sealed chamber enclosing the transducer and having an interior in fluid communication with the first stationary contact and the transducer. When an electrically conductive fluid is disposed within the chamber, the electrically conductive fluid creates a conduction path between the transducer and either the first rotational contact or the second rotational contact.

Other embodiments include a device for medical ultrasound which includes a transducer configured for transmitting and/or receiving ultrasound signals and operatively coupled with a drive shaft extending substantially along a rotation axis. The transducer rotates in response to rotation of the drive shaft. A motor is operatively coupled with the drive shaft, and includes a first slip ring assembly having a first rotational contact and a first stationary contact. The first rotational contact is fixed relative to the drive shaft and rotatable with the drive shaft relative to and in contact with the first stationary contact. The first slip ring assembly maintains an electrical conduction path between the first rotational contact and the first stationary contact when the drive shaft rotates.

Particular embodiments include the motor being a piezoelectric motor including a stator and a first clutch coupled with the shaft and disposed to engage a piezoelectric element, wherein the first clutch includes the first rotational contact. The stator can include the first stationary contact. The motor can include a second slip ring assembly having a second rotational contact and a second stationary contact. The second rotational contact can be fixed relative to the drive shaft and rotatable with the drive shaft relative to and in contact with the second stationary contact. The second slip ring assembly can maintain an electrical conduction path between the second rotational contact and the second stationary contact when the drive shaft rotates. The first rotational contact is electrically insulated from the second rotational contact and the first stationary contact is electrically insulated from the second stationary contact. The stator can include a first end and a second end, wherein the second end is positioned opposite the first end in an axial direction relative to the rotation axis. The first clutch can be disposed adjacent to the first end and the second clutch can be disposed adjacent to the second end. A first insulating layer can be positioned between the first stationary contact and the first end, and a second insulating layer can be positioned between the second stationary contact and the second end.

Other particular embodiments can include a second slip ring assembly having a second rotational contact and a second stationary contact, the second rotational contact being fixed relative to the drive shaft and rotatable with the drive shaft relative to and in contact with the second stationary contact. The second slip ring assembly can maintain an electrical conduction path between the second rotational contact and the second stationary contact when the drive shaft rotates. The first rotational contact can be electrically insulated from the second rotational contact. A first end of the first rotational contact can be disposed to contact the first stationary contact and a second end of the second rotational contact can be disposed to contact the second stationary contact, wherein during rotation of the drive shaft, the first end follows a first circumferential path about the rotation axis and the second end follows a second circumferential path about the rotation axis. The first circumferential path can be positioned concentric to and radially inward of the second circumferential path, and the first stationary contact can be positioned radially inward of the second stationary contact. In other embodiments, a first end of the first stationary contact is disposed to contact the first rotational contact and a second end of the second stationary contact is disposed to contact the second rotational contact. The second end is positioned radially outward from the first end relative to the rotation axis, and the second rotational contact is positioned concentric to and radially outward of the first rotational contact. A disk can be coupled with the shaft and anchoring the first and second rotational contacts. The first and second stationary contacts can be positioned in a plane which is normal to the rotation axis.

A biasing member can be disposed to apply a force which maintains contact between the first rotational contact and the first stationary contact. At least one of the contacts can be coated with a precious metal. An encapsulating structure fillable with a fluid can be positioned to enclose the slip rings whereby the fluid reduces friction and/or prevents oxidation.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-sectional view of an ultrasound imaging device with a slip ring assembly positioned on a control side of a motor.

FIG. **2** is a cross-sectional view of an ultrasound imaging device with a slip ring assembly positioned on an application side of the motor.

FIG. **2***a* is an enlarged view of a portion of the slip ring assembly of FIG. **2**.

FIG. **3** is a cross-sectional view of an ultrasound imaging device with a slip ring assembly positioned on an application side of the motor, and a fluid acting as a conductor.

FIG. **3***a* is an enlarged view of a portion of the slip ring assembly of FIG. **3**.

FIG. **4** is a cross-sectional view of an ultrasound imaging device with a slip ring assembly included in a motor.

FIG. **5** is a cross-sectional view of an ultrasound imaging device with a slip ring assembly included in a motor, and a fluid acting as a conductor.

FIG. **6** is a cross-sectional view of an ultrasound imaging device with a slip ring assembly positioned adjacent to an application side end of the motor.

DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

For the purpose of promoting an understanding of the principles of the disclosure, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the claims is thereby intended. Any alterations and further modifications in the described embodiments, and any further applications of the principles of the disclosure as described herein are contemplated as would normally occur to one skilled in the art to which the disclosure relates.

Referring generally to the drawings, there are shown embodiments of a device **20** suitable for endoluminal medical procedures. Device **20** can be used with a system that includes a console (not shown) and device **20**. In some cases the system can be an imaging system. The ultrasound console can be a type which is generally used for medical ultrasonic imaging, e.g. generally including control devices usable by a physician and a graphic display which displays graphical images obtained during an ultrasound procedure. Device **20** can be used for obtaining images at various locations of a body such as a blood vessel, urethra, ureter, vagina, rectum, throat, ear, or through an artificial tract (or lumen) by percutaneous puncture for example. The console portion can be connected to commercially available ultrasound probes or catheters with compatible pinout, or other medical devices which are configured for endoluminal procedures. Device **20** is capable of emitting and receiving ultrasound signals and then communicating data obtained from ultrasound signals to the console. The console is configured to process the data and create image(s) viewable on a display or other data output.

In the embodiment shown schematically in FIG. **1**, device **20** includes a catheter **22** or other flexible elongated member having a wall **24** defining an internal chamber **26**. Catheter **22** is sized and configured for insertion into and/or travel along bodily orifices or lumens. Positioned within chamber **26** is a transducer **28** and a motor **32** operatively coupled with transducer **28**. Generally, catheter **22** provides access to a bodily location where motor **32** provides rotational motion to transducer **28**. Device **20** could optionally include a motor housing (not shown) for providing structural support for motor **32** and transducer **28**. Transducer **28** in conjunction with rotary motion provided by motor **32** is capable of transmitting and receiving ultrasound signals in a variety of directions which are passed along data signal communication lines (i.e. conductors, or conduction pathways) between transducer **28** and the ultrasound console.

Catheter **22** in the illustrated embodiment is an elongated device of plastic or other sturdy flexible material which presents a barrier to the passage of ultrasound signals which is small enough that ultrasound images may be reasonably acquired through the barrier. Catheter **22** includes a control end which during use is nearest to the user and an application end which during use is nearest to the user's point of interest. The terms "control" and "application" are used throughout this description to describe these positional orientations. Wall **24** surrounds chamber **26**, which is at the application end of device **20** in the illustrated embodiment. The control end of wall **24** and/or catheter **22** may extend outside of the patient during use, (or may attach to another component that extends outside the patient), and may end in a handle or other operating portion for maneuvering catheter **22**. Particular embodiments of catheter **22** or at least chamber **26** are cylindrical, and are sized for insertion into and passage through bodily orifices and lumens, such as insertion into the femoral artery and passage through it toward the heart. Wall **24** may have a port or other feature to allow injection of fluid into chamber **26**, as will be discussed further below.

Catheter **22** is constructed of a material which is substantially echolucent when placed in the surrounding working environment (such as blood within a blood vessel) such that it acts as an acoustic window which allows passage of ultrasound signals with minimal attenuation. Echolucency is a result of an ultrasound wave conduction path having mediums with substantially matched acoustic impedances. For example, when used within a blood vessel containing body tissues and blood, it is preferable for catheter **22** to be constructed of a material which is structurally rigid and which has acoustic impedance similar to that of body fluids such as blood. Possible materials could include, for example, a polymer material such as high density polyethylene, polymethylpentene (PMP), or acrylonitrile butadiene styrene (ABS). It has been determined that in some cases the thickness of at least the portion of catheter **22** which serves as the viewing window can be approximately N/2 (where N is a positive integer) of the wavelength corresponding to center frequency.

Transducer **28** is indicated schematically in the drawings. The term "transducer" should be understood to include an assembly of two or more parts as well as a single piece. An exemplary transducer **28** includes a body or backing **40** with an ultrasound element **42** attached to one side of backing **40**, and one or more clamping rings **44**. Transducer **28** can include a matching layer (not shown) attached to one side of element **42**. Element **42** can be a piezoelectric element which has the ability to convert electrical energy into sound waves and sound waves into electrical energy. The positioning of element **42** as indicated, on a side of backing **40**, results in a directed ultrasound beam direction. Backing **40** may be substantially opaque to ultrasound signals, so that such signals are effectively only projected outward from element **42**, e.g. to one side or in a limited angular range radially (relative to a rotation axis) from backing **40**. The matching layer has acoustic impedance generally between that of element **42** and the medium surrounding transducer **28** in order to minimize mismatched acoustic impedance between transducer **28** and the medium surrounding transducer **28**. Transducer **28**, as discussed, can be a single element transducer which is capable of sending and receiving ultrasound waves in a range of frequencies which are typically used in medical ultrasound procedures, such as, for example, in the range from 20 KHz to 100 MHz. Clamping rings **44** have been determined to improve efficiency and add mechanical stability to transducer **28**.

Motor **32** is a microminiature motor of a small size which is suitable for containment within chamber **26** of catheter **22**. Microminiature motors such as small piezoelectric motors, electromagnetic motors, or shape memory motors may be used. In one embodiment, the motor is a three-phase, coreless, brushless DC electromagnetic motor, which has few components, small size and minimal complexity. Another embodiment includes a piezoelectric motor. A piezoelectric motor is preferably of a small size, such as having a diameter in the range from 0.3 mm to 4 mm. An advantage of a piezoelectric motor compared to other motors such as electromagnetic motors is that the efficiency of the piezoelectric motor is independent of size such that microminiature piezoelectric motors can exhibit a high torque-to-size ratio relative to other motors. The use of such microminiature motors can eliminate problems with torque cables

Motor **32** includes a rotating shaft **70**, for direct or indirect connection to transducer **28**. It has been determined that hall sensors are advantageous as a feedback mechanism because of their small size and mature design. In some embodiments, the ultrasound beam or signals emitted and/or received by transducer **28** is used as a feedback mechanism to precisely assess or monitor the rotational position of motor **32** (and the ultrasound beam rotated by it) relative to the rest of device **20**, ensuring proper registration of images obtained through transducer **28**. A seal **74**, bearing, or other structure is positioned adjacent to motor **32** and shaft **70** to provide a fluid seal between the motor and the chamber surrounding transducer **28**.

Shaft **70** can be a hollow cylindrical shaft in the illustrated embodiments, having a lumen **72** extending therethrough. Shaft **70** extends through the entirety of motor **32**. Lumen **72** permits passage of electrical conductors, (e.g. wires, cables, guide wires), mechanical operational items (e.g. guide wires), and/or other features to pass through shaft **70**, allowing transmission of electrical and/or mechanical force or energy through lumen **72** without affecting the rotation of shaft **70**. Transducer **28** is operatively connected to shaft **70** so that transducer **28** rotates in response to rotation of shaft **70**.

Transducer **28** is operatively coupled with shaft **70** in this embodiment so that its longitudinal axis is parallel to or coincident with the rotation axis of shaft **70**. Element **42** is positioned in this embodiment so that an ultrasound beam or signals emitted from element **42** travel outward from the rotation axis. Similarly, element **42** receives an ultrasound beam or signals from directions outward of the rotation axis. Transducer **28** can be coupled directly to shaft **70**. Alternatively, transducer **28** in one example could be coupled with shaft **70** through use of an intermediate support (not shown). The intermediate support can be hollow and defining an inner lumen in a similar manner as shaft **70**.

A portion of chamber **26** immediately surrounding transducer **28** extending towards the application end of catheter **22** can be completely filled with a fluid or other substance having acoustic impedance similar to that of blood, such as saline, oils (e.g. mineral oil or castor oil), or mixed alcohol. The substance should minimize friction acting against transducer **28** during rotation. In this way, acoustic matching can be achieved between body fluids, catheter **22**, and the medium immediately surrounding transducer **28**. Acoustic matching ensures that minimal signal losses occur when transmitting and receiving ultrasound signals between transducer **28** and body tissue which enhances the clarity of the resulting image.

The fluid can be added to device **20** during manufacture, or alternatively could be added prior to use. When the transducer is sealed and the coupling fluid is placed into the chamber during manufacture, long term contact with the parts necessitates a non-corrosive fluid such as mineral oil or castor oil in order to preserve the shelf life of the product. Preferably, the oil is bio-compatible, acoustically transparent, and has low viscosity. Alternatively, a fluid communication port positioned within the catheter or through the catheter wall can allow access for adding a fluid, in which case a corrosive fluid may be used. Corrosive fluids such as water, saline, and alcohol typically have more favorable combinations of bio-compatibility, acoustic transparency and viscosity.

In the embodiment of FIG. **1**, electronic signals pass between an ultrasound console and transducer **28** via fixed conductors (e.g. wires) **34**, **36**, and rotating conductors **50**, **52** connected to transducer **28** and extending through lumen **72** in rotatable shaft **70**. A pair of slip ring assemblies **60**, **62** facilitate transfer of such signals between rotating conductors **50**, **52** and non-rotating conductors **34**, **36**. In the FIG. **1** embodiment, two slip ring assemblies **60**, **62** each having a single conduction path are shown. However, a design could include a single slip ring assembly that includes one or two conduction paths. In the FIG. **1** embodiment, a two channel electrical connection includes conductor **50** as a signal channel and conductor **52** as a ground channel. Conductors **50**, **52** can be attached at a variety of locations to element **42**, depending on the requirements of the particular configuration. Conductors **50**, **52** can be thin wires which extend through backing **40** and/or clamping rings **44** and into lumen **72**. Alternatively, conductors **50**, **52** can extend from the sides of transducer **28** and sealingly enter lumen **72** through a sealed port (not shown). Alternatively, backing **40** can be conductive so that the whole backing is part of the conduction path between the element **42** and one or both conductors **50**, **52**. Similarly, the matching layer could be a conductive layer which is part of the conduction path between element **42** and one or both conductors **50**, **52**.

Slip ring assemblies **60**, **62** include stationary contacts **64**, **66** and rotational contacts **68**, **69**. In the FIG. **1** embodiment, stationary contacts **64**, **66** are conductive filaments and rotational contacts **68**, **69** are conductive rings positioned around the circumference of shaft **70**. However, in other embodiments rotational contacts **68**, **69** could be filaments and stationary contacts **64**, **66** could be conductive rings. The conductive rings include a conductive circle or band fixed to shaft **70** and insulated from each other (and from shaft **70** in embodiments in which shaft **70** is electrically conductive). The conductive rings are disposed to maintain contact with the filaments even when shaft **70** rotates, transferring electric signals between the rotating portion and the stationary portion. Slip ring assemblies using components other than filaments are also contemplated, such as the use of fixed (e.g. spring) contacts or brushes for example.

Slip ring assemblies **60**, **62** maintain a conduction pathway between stationary contacts **64**, **66** (connected to fixed conductors **34**, **36**) and rotational contacts **68**, **69** (connected to rotating conductors **50**, **52**) during rotation through use of the sliding contact between the stationary contacts and the conductive surface of the rotational contacts. A portion of rotational contacts **68**, **69** can pass through the wall of shaft **70** to couple with conductors **50**, **52**. Alternatively, conductors **50**, **52** can pass through the wall of shaft **70** to couple with rotational contacts **68**, **69**. Conductors **50**, **52** can be attached to rotational contacts **68**, **69** through soldering or other techniques. Ends of conductors **34**, **36** are conductively attached to stationary contacts **64**, **66** using similar techniques. The conductors **34**, **36** pass through a lateral wall **78** and extend throughout the catheter **22** to eventually conductively connect with the ultrasound console. In the embodiment of FIG. **1**, slip ring assemblies **60**, **62** are each positioned on the control side of motor **32**, i.e. their respective contacts are on or adjacent to a portion of shaft **70** extending from the control side from motor **70**.

During operation of the device **20**, a physician moves device **20** into the body (e.g. the circulatory system) and positions device **20** and catheter **22** within the body of a patient at a desired location. Once device **20** is properly positioned, motor **32** is powered such that shaft **70** rotates, e.g. at a uniform angular velocity. Correspondingly, transducer **28** rotates about the rotation axis. Element **42** is energized through conductors **50**, **52** which receives power from the ultrasound console. Element **42** transmits an ultrasound signal substantially in an outward direction relative to shaft **70** in this embodiment, i.e. substantially perpendicular to the rotation axis.

When an ultrasound signal is transmitted, the ultrasound signal passes across wall **24** of catheter **22** until it encounters an acoustic impedance boundary (e.g. body tissue, plaque, or other material which has acoustic impedance sufficiently different from bodily fluids or other surrounding material) such that the ultrasound signal is partially reflected at the surface of the body tissue. A portion of the ultrasound signal is reflected back towards transducer **28**. Simultaneously or subsequently transducer **28** continues to transmit further ultrasound signals and the process is repeated, continuously in certain embodiments over a desired period of time.

Transducer **28** is rotated about the rotation axis such that the ultrasound beam moves in a sweeping direction which takes the form of a slice, cone, or toroidal shape. In this manner, while transducer **28** rotates about the rotation axis, element **42** is able to emit and receive ultrasound signals sufficient for the ultrasound imaging system to create a 2D image representative of bodily tissue adjacent to or near catheter **22**. According to the specifics of the ultrasound imaging procedure or the desires of the physician performing the procedure, the device **20** can be moved in an axial direction within a bodily orifice such that multiple two-dimensional images are created at different locations within the bodily orifice. In this way, the two dimensional images can be processed into a three dimensional image or alternatively the physician can gain a three dimensional conceptual understanding of the physical features of bodily tissue adjacent to catheter **22**.

An alternative embodiment of device **20** is shown schematically in FIG. **2**. Device **20** includes a bearing **90** which has integrated slip ring assemblies **80**, **82**. Bearing **90** in FIG. **2** is not drawn to scale and is included merely for illustrative purposes in order to visually depict the embodiment described herein. Bearing **90** has stationary contacts **84**, **86** and rotational contacts **88**, **89**. Stationary contacts **84**, **86** may be brushes, as noted above, or may be formed by applying a conductive coating to a non-conductive bearing surface such as a polymer or ceramic. It has been determined that cobalt-doped gold (e.g. hard gold) is a good candidate for a conductive plating material because of its low resistance electrical connection and favorable mechanical wearing properties. Other plating materials could also be used, such as precious metals, platmium or rhodium for example. A nonconductive section **96** (or stationary insulating section) of bearing **90** is maintained between stationary contact **84** and stationary contact **86** as an insulative section.

Rotational contacts **88**, **89** are fixed to shaft **70** and so rotate along with shaft **70**. In this embodiment, each contact **88**, **89** is a layer of conductive material, and they are separated by a central layer **98** of insulating material. Each layer may be applied separately, or as another example can be formed from a three-layer coating which is added to the surface of shaft **70**. Rotational contact **89** is a base layer on the surface of shaft **70**, or if shaft **70** is conductive, is over an insulating layer (not shown) on the surface of shaft **70**. Insulating layer **98** (i.e. a second or central layer) is applied at least partially over rotational contact **89**. The outer edge portions of the conductive layer of rotational contact **89** are exposed with respect to layer **98** in this embodiment (i.e., portions extending in an axial direction relative to the rotation axis and further than the edges of layer **98**), so that contact **89** can conductively interact with stationary contact **86**. Rotational contact **88** is applied on central layer **98**, with two outer edge portions of central layer **98** exposed from contact **88** in this embodiment so as to maintain insulation between rotational contact **88** and rotational contact **89**. Rotational contacts **88**, **89** align with and contact stationary contacts **84**, **86**, respectively. Thus, this embodiment of contacts **88**, **89** and layer **98** essentially form a sandwich with insulating central layer **98** between contacts **88**, **89**, and with exposed outer (or outward) portions of contacts **88**, **89** contacting stationary contacts **84**, **86**.

Conductors **92**, **94** conductively couple transducer **28** to rotational contacts **88**, **89**. Rotational contacts **88**, **89** conductively couple with stationary contacts **84**, **86**. Stationary contacts **84**, **86** are connected to fixed conductors (e.g. wires or cable(s)) which extend through lateral wall **76** and which are electrically operatively coupled with the ultrasound console.

A further alternative embodiment of device **20** is shown schematically in FIG. **3**. In this embodiment, device **20** includes a fluid conductor **110** and a wired conductor **112**. Device **20** includes bearing **100** which is similar to the embodiment of FIG. **2**, however it does not include a third layer as part of the rotational contact. Additionally, the central insulative layer **106** positioned on shaft **70** extends in the application side direction to sealingly isolate rotational contact **102** from any fluid positioned adjacent to bearing **100**. Conductor **112** can pass through backing **40**, and/or clamping ring **44**, and a wall of shaft **70** in order to conductively couple with rotational contact **102**. Conductor **110** provides an electric conduction path between element **42** and stationary contact **104**. Alternatively, the matching layer could be a conductor which is part of a conduction path between element **42** and conductor **110**. Conductor **110** can be any of a variety of electrically conductive fluids. Testing has shown that 10× concentrated phosphate buffered saline is one suitable conductive fluid. Conductor **110** has acoustic properties similar to wall **24** and body fluids in order to provide matching acoustic characteristics between conductor **110**, wall **24**, and body fluids, as well as lubricious qualities and other characteristics as described in relation to the embodiment of FIG. **1**. The FIGS. **2** and **3** embodiments provide the advantage that device **20** can be smaller and more compact by positioning slip rings between transducer **28** and motor **32**.

A further alternative embodiment of device **20** is shown in FIG. **4**. In this embodiment, electric signals are passed between the ultrasound console and transducer **28** via fixed conductors **115**, **116** and rotating conductors **117**, **118** connected to transducer **28** and extending through lumen **72** in rotatable shaft **70**. A piezoelectric motor **120** has slip ring assemblies **122**, **124** incorporated into it. Slip ring assemblies **122**, **124** include stationary contacts **130**, **132** and rotational contacts **134**, **136**. Slip ring assemblies **122**, **124** facilitate transfer of signals between stationary contacts **130**, **132** and rotational contacts **134**, **136**.

Motor **120** is of a type which uses a piezoelectric element capable of converting between mechanical and electrical energy to provide a driving vibrational motion. A stator **125** is secured to wall **24** such that it doesn't rotate relative to wall **24**. The piezoelectric element is incorporated into stator **125**. In some designs, the piezoelectric element could be constructed as stator **125**. In other designs one or more piezoelectric elements could be attached to stator **125**. Clutches are positioned at either axial end of stator **125** and are disposed on shaft **70** such that they rotate with shaft **70** and are rotatable relative to stator **125**. A spring **138** ensures that the clutches and stator **125** are always in contact with relatively constant force. In a typical arrangement, an energized piezoelectric element will act upon the clutches and cause the clutches to rotate relative to the stator. In this embodiment, the mechanical connection between the clutches and stator are used to create a slip ring. Accordingly, the clutches also serve as rotational contacts **134**, **136**. Shaft **70** is constructed from an electrically insulating material or alternatively, an insulative coating can be added between rotational contacts **134**, **136** and shaft **70** in order to electrically isolate rotational contact **134** from rotational contact **136**. Stationary contacts **130**, **132** are positioned in mechanical connection with rotational contacts **134**, **136** and are generally disc shaped and extend circumferentially around the rotation axis. The stationary and rotational contacts are created of a material which is suitable for conducting electrical signals which is usually but not necessarily a metal. In some cases, the contacts could be coated with a conductive layer. Insulating layers **126**, **128** are positioned between stator **125** and stationary contacts **130**, **132**. Insulating layers **126**, **128** are generally disc shaped and extend circumferentially around the rotation axis. Insulating layers **126**, **128** are created of any suitably electrically insulating material (and/or an insulative coating) and provide electrical insulation between stationary contacts **130**, **132** and stator **125**.

Slip ring assemblies **122**, **124** provide a conduction pathway between stationary contacts **130**, **132** and rotational contacts **134**, **136**, which is a part of a conduction pathway between transducer **28** and the ultrasound console. Conductor **117** is connected to rotational contact **136**, and conductor **118** is connected to rotational contact **134**. Conductor **115** is connected to stationary contact **130**, and conductor **116** is connected to stationary contact **132**. Conductors **117**, **118** are configured to pass through the wall of shaft **70** and couple with rotational contacts **134**, **136** using any suitable means which provides insulation between the conductors and the shaft wall, such as for example using insulated wires. Conductors **115**, **116** extend throughout the catheter **22** to eventually conductively connect with the ultrasound console. Rotational contacts **134**, **136** and stationary contacts **130**, **132** each have a surface which is suitable to maintain a mechanical connection between the rotational contacts and stationary contacts even while rotational contacts **134**, **136** rotate relative to stationary contacts **130**, **132**. A suitable metallic coating or lubrication could be used for example.

The design of FIG. **4** is advantageous because it minimizes the extra space and components needed to incorporate a slip ring into device **20**. Two slip ring assemblies **122**, **124** are included. However, the design could be described as a single slip ring assembly that includes both conduction paths. In the FIG. **4** embodiment, a two channel electrical connection includes conductor **117** as a signal channel and conductor **118** as a ground channel. Conductors **117**, **118** can be attached to transducer **28** in a variety of ways as described herein.

A further alternative embodiment of device **20** is shown in FIG. **5**. In this embodiment electric signals are passed between the ultrasound console and transducer **28** via conductors **145**, **146**, **147**, **148**. A piezoelectric motor **121** has a one channel slip ring assembly **149** incorporated into it. The slip ring assembly **149** includes stationary contact **150** and rotational contact **154**. The slip ring assembly **149** facilitates transfer of signals between stationary contact **150** and rotational contact **154**.

Motor **121** is a piezoelectric motor as described previously. A stator **156** has at one end a stationary contact **150**. Stator **156** is secured to wall **24** such that it doesn't rotate relative to wall **24**. The piezoelectric element is incorporated into stator **156** as described previously. Rotational contact **154** serves as a clutch positioned on the application side end of stator **156**. An additional clutch **152** is positioned on the contact side end of stator **156**. Rotational contact **154** and clutch **152** are disposed on shaft **70** such that they rotate with shaft **70** and are rotatable relative to stator **156**. A spring **158** ensures that rotational contact **154** and clutch **152** are always in contact with stator **156** with relatively constant force. An energized piezoelectric element will act upon one or both of rotational contact **154** and clutch **152** and cause rotational contact **154** and clutch **152** to rotate relative to stator **156**. The mechanical connection between rotational contact **154** and stator **156** (stationary contact **150**) is used to create a slip ring. Rotational contact **154** and stator **156** are created of a material which is suitable for conducting electrical signals which is usually but not necessarily a metal. Additionally, stationary contact **150** and rotational contact **154** each have a surface which is suitable to maintain a mechanical connection between rotational contact **154** and stationary contact **150** even while rotational contact **154** rotates relative to stationary contact **150**. In some cases, rotational contact **154** and stator **156** could be coated with a conductive layer or lubrication. A suitable metallic coating could be applied for example, such as cobalt-doped gold, platmium, or rhodium for example.

Conductor **148** is a fluid conductor. A seal **160** or other structure is positioned near motor **121** and shaft **70** to provide a fluid seal between the motor and the chamber **26** surrounding transducer **28**. Conductor **145** is conductively coupled with conductors **148** and is disposed to sealingly pass through seal **160**. Conductor **148** provides an electric conduction path between an element **42** of transducer **28** and conductor **145**. Alternatively, a matching layer could be a conductor which is part of a conduction path between element **42** and conductor **148**. Conductor **148** can be any of a variety of electrically conductive fluids as discussed previously. Conductor **110** has acoustic properties similar to wall **24** and body fluids in order to provide matching acoustic characteristics between conductor **148**, wall **24**, and body fluids, as well as lubricious qualities and other characteristics as described in relation to the embodiment of FIG. **1**.

Slip ring assembly **149** provides a one channel conduction pathway between stator **156** and rotational contact **154** which is part of a two channel conduction pathway between transducer **28** and the ultrasound console. The first pathway has a rotatable portion which extends from transducer **28** via conductor **147** through shaft **70** to rotational contact **154**. The first pathway then extends through stator **156** and conductor **146**. The second pathway extends from transducer **28** through fluid conductor **148** to conductor **145**. Conductors **145**, **146** extend throughout the catheter **22** to eventually conductively connect with the ultrasound console.

The design of FIG. **5** is advantageous because it minimizes the extra space and components needed to incorporate a slip ring into device **20** as well as reducing complexity of motor **121**. In the FIG. **5** embodiment, a two channel electrical connection includes conductor **148** as a signal channel and conductor **147** as a ground channel, or vice versa. Conductor **147** can be attached to transducer **28** in a variety of ways as already described.

The design of FIG. **5** which includes as one channel a conductive fluid surrounding transducer **28** could be incorporated into each embodiment described herein by creating each various slip ring assembly as a one channel conductor and using conductive fluid as a second channel.

A further alternative embodiment of device **20** is shown in FIG. **6**. In the embodiment of FIG. **6**, electronic signals pass between an ultrasound console and transducer **28** through both a fixed conduction pathway and a rotatable conduction pathway which are joined by a slip ring assembly **164** which is incorporated with or attached to a motor **162**. Slip ring assembly **164** includes rotational contacts **182**, **184** and stationary contacts **178**, **180**. Slip ring assembly **164** and motor **162** are configured to be disposed in device **20** in a similar manner as previously described (e.g. within catheter **22**). Slip ring assembly **164** is a type having a rotating surface and a stationary surface positioned parallel to each other and normal to the rotation axis. Each surface carries conductors which interact with conductors on the opposing surface. This is sometimes referred to as a pancake-style slip ring assembly.

Motor **162** is a microminiature motor of a small size as previously described, and could be a piezoelectric motor, electromagnetic motor, or shape memory motor, for example. Motor **162** is operatively coupled with a rotatable shaft **166**. Shaft **166** can be solid or a hollow cylindrical shaft having a lumen extending therethrough. Transducer **28** is operatively connected to shaft **166** so that transducer **28** rotates in response to rotation of shaft **166**.

Conductors **170**, **172** are incorporated with motor **162** through use of a PCB cable or other suitable means. In the FIG. **6** example, a PCB cable **174** runs along a stator or outer portion of motor **162** from a control side of motor **162** to an application side end of motor **162**. The PCB cable **174** extends throughout catheter **22** to conductively couple with an ultrasound console. A shoulder **176** is positioned on the application side end of motor **162**, and more particularly on the application side end of the stator of motor **162**. Shoulder **176** includes stationary contacts **178**, **180** which extend circumferentially about the rotation axis in an annular configuration. Stationary contacts **178**, **180** are exposed portions of conductive material (e.g. metal) which are configured to mechanically interact with rotational contacts **182**, **184**. Stationary contact **178** is positioned radially outward from stationary contact **180** with respect to the rotation axis. In other words, stationary contacts **178**, **180** are arranged concentrically with respect to the rotation axis. Shoulder **176** can include a separate disk positioned at the application side end of motor **162**. Alternatively shoulder **176** can be an integral part of cable **174** wherein the application side end of cable **174** is shaped as a disk shaped shoulder **176**. Stationary contact **178** is conductively coupled with conductor **170** and is electrically insulated from stationary contact **180**. Conductor **172** is electrically insulated from stationary contact **178** and conductor **170**. Stationary contact **180** is conductively coupled with conductor **172**.

A disk **168** is coupled with shaft **166** such that it is substantially normal relative to the rotation axis. Disk **168** includes a centrally positioned hole which is sized to fit shaft **166**. Alternatively, disk **168** can be an integral part of shaft **166**. Disk **168** can be connected to shaft **166** by glue or any other suitable means. Disk **168** rotates along with shaft **166** such that it rotates relative to shoulder **176**. Disk **168** is positioned substantially parallel to shoulder **176**. Disk **168** includes holes **186**, **188** which are configured to accept and anchor rotational contacts **182**, **184**. Disk **168** can be constructed of any suitably rigid material, such that it substantially maintains its shape while shaft **166** rotates. Disk **168** can be constructed of a suitable nonconductive material such that it does not provide a conduction path between rotation contact **182** and rotation contact **184**. Alternatively disk **168** can include an insulative coating.

Rotational contacts **182**, **184** extend from disk **168** to mechanically couple with stationary contacts **178**, **180**. Rotational contact **182** is positioned radially outward from rotational contact **184** relative to the rotation axis. Rotational contact **182** is positioned to mechanically interact with stationary contact **178** and rotational contact **184** is positioned to mechanically interact with stationary contact **180**. Rotational contacts **182**, **184** can be any suitable contact such as a metal filament or wire. Rotational contacts **182**, **184** include ends **190**, **192** which are positioned to maintain a mechanical connection with stationary contacts **178**, **180** while disk **168** rotates. Rotational contacts **182**, **184** extend axially from disk **168** in a control side direction towards shoulder **176** and include bends **194**, **196** near the control side of the contacts which facilitate the mechanical connection with stationary contacts **178**, **180**. Bends **194**, **196** can be configured to cause elastic force to apply pressure between ends **190**, **192** and stationary contacts **178**, **180**. In this way, rotational contacts **182**, **184** form a slipping electrical contact with stationary contacts **178**, **180** which allow rotational contacts **182**, **184** to maintain a conductive coupling with stationary contacts **180**, **182** while transducer **28** rotates. Conductor **198** is coupled with the application side of rotational contact **184** and conductor **200** is coupled with the application side of rotational contact **182**. Conductors **198**, **200** can be coupled with rotational contacts **182**, **184** using any suitable means such as soldering for example.

Slip ring assembly **164** provides a two channel conduction pathway between rotational contacts **182**, **184** and stationary contacts **178**, **180** which is part of a conduction pathway between transducer **28** and the ultrasound console. Conductors **198**, **200** can extend through an optional hole in the wall of shaft **166** and continue through a shaft lumen to couple with transducer **28**. Conductors **170**, **172** extend throughout the catheter **22** to eventually conductively connect with the ultrasound console. PCB cable **174** may or may not extend throughout the length of catheter **22**. Rotational contacts **182**, **184** and stationary contacts **180**, **182** each have connection surfaces which are suitable to maintain a mechanical connection between rotational contacts and stationary contacts even while rotational contacts **182**, **184** rotate relative to stationary contacts **178**, **180**. A suitable metallic coating or lubrication could be used for example.

The design of FIG. **6** is advantageous because it minimizes the extra space and components needed to incorporate a standalone slip ring into device **20**. Slip ring assembly **164** is described with a two channel connection. However the slip ring design could incorporate a single channel connection in which a second channel could include a conductive fluid surrounding transducer **28** and a conductor extending from the fluid through the catheter to the control side of motor **162** (as described herein).

In an alternative embodiment (not shown), slip ring assembly **164** could include axially-protruding contacts **182**, **184** being positioned on shoulder **176** and conductively coupled with conductors **170**, **172**. In that case, contacts **182**, **184** are stationary relative to the rotation axis and are configured to interact with annular and concentrically-arranged rotational contacts positioned on disk **168** and which are conductively coupled with conductors **198**, **200**. In this embodiment, ends **190**, **192** form a sliding contact with the rotational contacts positioned on the disk **168** as disk **168** rotates about the rotation axis.

The embodiments described herein, including use of slip ring assemblies, allows device **20** to include a directly rotating transducer element which avoids the need for use of a rotating mirror design and the disadvantages associated with such design. For example, device **20** is shorter and takes up less space than a rotating mirror design. The directly rotating transducer embodiments described herein have a deeper acoustic focal depth than a rotating mirror design. In the disclosed embodiment, ultrasound waves are generated in a generally radial direction with respect to the rotation axis (i.e. the catheter axis) as opposed to a reflector design in which ultrasound waves must travel axially (relative to the rotation axis) for several millimeters before beginning to travel in a radial direction.

The slip ring embodiments described herein are not limited to the uses described herein. For example, the slip ring assemblies can be incorporated in any ultrasound device which incorporates a rotating element. Some examples could include a linear motor with a rotary drive shaft, a linear motor which connects to mechanical connections to convert linear movement to rotary movement, or a gearing assembly positioned between a drive shaft and a transducer.

As an additional advantage, device **20** facilitates capture of an image through a viewing window which is free from unnecessary artifacts, obstructions, or errors within the image. For example, positioning of transducer **28** at a location which is on an application side of motor **32**, conductors **50**, **52**, and other components ensures that wires or other echogenic materials are not positioned within or across the viewing window of transducer **28**, even as transducer **28** rotates in a full 360° rotation. In this way, there are no wires or other echogenic materials which could cause artifacts within the image or block portions of the redirected ultrasound waves, which provides the physician a clear view of the entirety of the viewing window. As used herein, the term "window" includes an obstruction-free pathway extending throughout the structure of device **20** and optional surrounding bodily fluid and/or tissue between transducer **28** and tissue which is to be imaged.

As an additional advantage, motor **32** which is separate from and positioned near the application end of a catheter allows a uniform angular velocity to be achieved by transducer **28**. This uniform angular velocity results in an ultrasound image which is free from non-uniform rotational defects (NURD) which can otherwise be a problem with the designs using torque cables and relatively remote motors or rotational power sources.

Device **20** is configured to be used with existing medical devices which are designed for percutaneous, intraluminal, or interstitial procedures. For example, device **20** can be used with a variety of commercially available catheters, e.g. positioned on or within an application side of a catheter depending on the particular configuration. Device **20** can be positioned within an existing lumen within the catheter. In an alternative embodiment, device **20** could include an external casing which is similar to catheter **22** having walls **24** but being shortened so as to compactly contain device **20**. Device **20** could be mounted externally to a catheter using a variety of mounting devices, glues or other types of arrangements. It will be understood by those skilled in the art that the particular type of mounting procedure for the device **20** to an existing medical device can include a variety of different types of mounting methods. Accordingly, the particular methods described herein are not indicative of any limiting aspects of the usage capabilities of the device **20**.

Other features may be included with the embodiments noted herein such as indexing systems, three-dimensional ultrasound devices, and gearing assemblies. Either one or both of the rotational contacts and stationary contacts disclosed herein can include a biasing member disposed to maintain sufficient force between the stationary contacts and rotational contacts. The contacts in all cases can include a coating including precious metals or other suitable material which prevents or minimized oxidation. In each embodiment, the slip ring assemblies can include an encapsulating structure which can be filled with a fluid to reduce friction between the rotational contacts and stationary contacts and/or prevent oxidation.

While device **20** is described in part above in the context of ultrasound system applications, it will be understood that embodiments of device **20** could also be used for other medical procedures and/or with a variety of other medical devices. The versatility of the embodiments described herein allows device **20** to be used to guide percutaneous therapeutic interventions such as for example embolism coils, stents, filters, graphs, balloons, biopsies, and ministering therapeutics, etc. Device **20** can be used to locate various anatomical landmarks that will be used to correctly place or guide therapy. Typical landmarks include confluences, bifurcations, side branches, nearby vessels, nearby nerves, the heart, and other tissues adjacent to vessels or other orifices containing the IVUS transducer. Device **20** can also be used to locate diseased tissue that will be treated or avoided. Device **20** can be used during a biopsy to provide an image of a needle being deployed into tissue. During a TIPS procedure an image can be produced to allow a physician to watch a needle being placed into the portal vein. For AAA delivery, device **20** can allow a physician to place a guide wire into a contralateral leg. Device **20** could also be used to image the location of a deployed implantable device both during and after deployment.

Although particular materials were highlighted herein for some components of the device **20**, those materials are not intended to be limiting of the types of materials which are suitable to be used in the device **20**. Additionally, where materials have were not highlighted, a variety of materials could be used such as certain types of metals, polymers, ceramics or other types of materials which are suitable for use in devices for subcutaneous use as well as IVUS imaging procedures.

The device **20** could also be used for a variety of other medical procedures and with a variety of other medical devices. It will be understood by those skilled in the art that the particular type of mounting procedure can include a variety of different types of mounting methods. Accordingly, the particular methods described herein are not indicative of any limiting aspects of the usage capabilities of the device **20**.

While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only the preferred embodiments have been shown and described and that all changes, equivalents, and modifications that come within the spirit of the inventions defined by the following claims are desired to be protected. It will be understood that structures or other features described with respect to one particular embodiment or item may be used in connection or along with other features, items or embodiments included herein. Alternative embodiments of device **20** include various configurations of slip ring assemblies disclosed herein. The structural and operational details disclosed herein are intended to apply to each embodiment with the exception of the specific differences described herein between the various embodiments.

What is claimed is:

1. A medical ultrasound device, comprising:

a motor operatively coupled with a drive shaft extending substantially along a rotation axis, wherein operation of the motor rotates the drive shaft around the rotation axis;

a transducer configured for transmitting and/or receiving ultrasound signals and operatively coupled with the drive shaft so that the transducer rotates in response to rotation of the drive shaft;

a first slip ring assembly having a first rotational contact and a first stationary contact, the first rotational contact being fixed to the drive shaft and rotatable with the drive shaft relative to and in contact with the first stationary contact, wherein the first slip ring assembly maintains an electrical conduction path between the first rotational contact and the first stationary contact when the drive shaft rotates;

a second slip ring assembly having a second rotational contact and a second stationary contact, the second rotational contact being fixed to the drive shaft and rotatable with the drive shaft relative to and in contact with the second stationary contact, wherein the second slip ring assembly maintains an electrical conduction path between the second rotational contact and the second stationary contact when the drive shaft rotates; and

wherein the first and second rotational contacts are electrically conductive layers fixed with respect to the drive shaft, further comprising an insulating layer wherein the first rotational contact is positioned radially inward of the second rotational contact, and the first and second rotational contacts are separated by the insulating layer, wherein the first rotational contact and the insulating layer have respective lengths measured parallel to a rotation axis of the drive shaft, and wherein the length of the first rotational contact is larger than the length of the insulating layer, wherein at least one axially outer portion of the first rotational contact is exposed from the insulating layer, wherein the second rotational contact has a length measured parallel to a rotation axis of the drive shaft, and wherein the length of the insulating layer is larger than the length of the second rotational contact.

2. The device of claim **1**, wherein two axially outer portions of the insulating layer are exposed from the second rotational contact.

3. The device of claim **1**, wherein the first stationary contact is integrally attached to the motor.

4. The device of claim **1**, wherein the medical ultrasound device includes an application side and a control side, and wherein the first rotational contact and first stationary contact are in contact with each other at a point on the application side of the insulating layer, and the second rotational contact and second stationary contact are in contact with each other at a point on the control side of the insulating layer.

5. The device of claim **1**, further comprising an insulating section disposed between the first stationary contact and the second stationary contact, and disposed to contact the insulating layer.

6. The device of claim **1**, wherein the first and second rotational contacts are part of a three layer coating, the first rotational contact being a radially inward first layer, the insulating layer being a second layer, and the second rotational contact being a radially outward third layer, wherein the insulating layer partially covers the first rotational contact and the second rotational contact partially covers the insulating layer.

7. The device of claim **1**, further comprising a fluidly sealed chamber enclosing the transducer and having an interior in fluid communication with the first stationary contact and the transducer, wherein the chamber is configured to receive a fluid, whereby when an electrically conductive fluid is disposed within the chamber, the electrically conductive fluid creates a conduction path between the transducer and either the first stationary contact or the second stationary contact.

8. The device of claim **1**, further comprising a biasing member disposed to apply a force which maintains contact between the first rotational contact and the first stationary contact.

9. The device of claim **1**, further comprising an encapsulating structure fillable and positioned to enclose at least one slip ring assembly with a fluid whereby the fluid reduces friction and/or prevents oxidation.

10. A medical ultrasound device, comprising:

a transducer configured for transmitting and/or receiving ultrasound signals and operatively coupled with a drive shaft extending substantially along a rotation axis, wherein the transducer rotates in response to rotation of the drive shaft; and

a motor operatively coupled with the drive shaft, wherein the motor includes a first slip ring assembly having a first rotational contact and a first stationary contact, the first rotational contact being fixed relative to the drive shaft and rotatable with the drive shaft relative to and in contact with the first stationary contact, the motor further comprising a stator, wherein the first stationary contact is incorporated into the motor and fixed relative to the stator, wherein the first slip ring assembly maintains an electrical conduction path between the first rotational contact and the first stationary contact when the drive shaft rotates;

wherein the motor further comprises a second slip ring assembly having a second rotational contact and a second stationary contact, the second rotational contact being fixed relative to the drive shaft and rotatable with the drive shaft relative to and in contact with the second stationary contact, wherein the second slip ring assembly maintains an electrical conduction path between the second rotational contact and the second stationary contact when the drive shaft rotates, wherein the first rotational contact is electrically insulated from the second rotational contact and the first stationary contact is electrically insulated from the second stationary contact; and,

wherein the motor is a piezoelectric motor including a stator and a first clutch coupled with the shaft and disposed to engage a piezoelectric element, wherein the first clutch includes the first rotational contact, the motor further comprising a second clutch coupled with the shaft, wherein the second clutch includes the second rotational contact, wherein the stator includes a first end and a second end, wherein the second end is positioned opposite the first end in an axial direction relative to the rotation axis, wherein the first clutch is disposed adjacent to the first end and the second clutch is disposed adjacent to the second end.

11. The device of claim **10**, wherein the stator includes the first stationary contact.

12. The device of claim **10**, further comprising a first insulating layer positioned between the first stationary contact and the first end, and a second insulating layer positioned between the second stationary contact and the second end.

13. The device of claim **10**, further comprising a first end of the first rotational contact disposed to contact the first stationary contact and a second end of the second rotational contact disposed to contact the second stationary contact, wherein during rotation of the drive shaft, the first end follows a first circumferential path about the rotation axis and the second end follows a second circumferential path about the rotation axis, wherein the first circumferential path is positioned concentric to and radially inward of the second circumferential path, and wherein the first stationary contact is positioned radially inward of the second stationary contact.

14. The device of claim **10**, further comprising a first end of the first stationary contact disposed to contact the first rotational contact and a second end of the second stationary contact disposed to contact the second rotational contact, wherein the second end is positioned radially outward from the first end relative to the rotation axis, and wherein the second rotational contact is positioned concentric to and radially outward of the first rotational contact.

15. The device of claim **13**, further comprising a disk coupled with the shaft and anchoring the first and second rotational contacts.

16. The device of claim **10**, further comprising a conductor and a fluidly sealed chamber enclosing the transducer and having an interior in fluid communication with the conductor and the transducer, wherein the chamber is configured to receive a fluid, whereby when an electrically conductive fluid is disposed within the chamber, the electrically conductive fluid creates a conduction path between the transducer and the conductor.

17. The device of claim **10**, further comprising a biasing member disposed to apply a force which maintains contact between the first rotational contact and the first stationary contact.

18. The device of claim **10**, wherein at least one of the contacts is coated with a precious metal.

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